Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-01 Room:301B Time:May 26 08:30-08:47

Magnetic modeling of fields from internal and external sources at the Earth, Moon and Mars

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Effective modeling of spacecraft magnetic field observations presupposes answers to the following questions: 1) is the region source-free?, 2) what is a natural coordinate system for the magnetic field being described? 3) what is the distribution in time and space of the observations? 4) what are the time and space characteristics of the coeval solar wind? Magnetic fields encountered by spacecraft have multiple origins, and each of these fields will often have a natural coordinate system. The origin of these magnetic fields can be classified into the following general categories: 1) spacecraft, 2) magnetopause, 3) magnetotail, 4) field-aligned currents, 5) magnetodisk currents 5) core, 6) lithosphere (remanent and induced), 7) induced fields, 8) motional induction fields. Modeling strategies are either sequential in approach, usually from the largest to smallest fields, or involve coestimation of fields of multiple origins. I will discuss examples from the Moon and Mars.

Keywords: mars, moon, magnetic fields, modeling, earth, spacecraft

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SEM001-02 Room:301B Time:May 26 08:47-09:02

Global marine magnetic data set and improvement of its accuracy

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I have been making efforts to expand our digital global marine data set to contribute to the World Digital Magnetic Anomaly Map (WDMAM) project. After creating a data set using digital GEODAS marine track line data stored at the U.S. National Geophysical Data Center together with some European colleagues (Quesnel et al., 2009), we collected new marine magnetic data for areas around Antarctica from the first ADMAP compilation, north Atlantic area compiled by Collette et al. (1984) and various oceanic areas from surveys by the IFREMER, the BGR, the British National Oceanography Centre, Spain, the JAMSTEC, etc. I have also digitized analog GEODAS data for about 30 cruises, and added them to our data set. The compiled data set now consists of about 37 million records from some 3000 cruises. Magnetic anomalies were recalculated using a comprehensive main and external field model CM4 (Sabaka et al., 2004), and were cleaned by careful check and removal of spurious data.

The RMS crossover difference (COD) of the whole data set is 82 nT, significantly greater than a typical observation error. If the accuracy of the reference main and external field model improves, the accuracy of the anomalies also increases. The CM4 model was obtained using satellite and observatory data, which have large gaps in oceanic areas. I investigated possibilities of the improvement of the model in oceanic areas, and tried to calculate corrections of secular variation of the main field model in oceanic areas using COD data of our marine data set. More details on the results are shown.

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SEM001-03 Room:301B Time:May 26 09:02-09:19

Crustal Magnetism and Effects of Exsolution Lamellae on Magnetic Properties: Importance of Remanent Magnetic Anomalies

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Magnetic anomalies from crustal sources are measured over a wide range of scales and elevations, from near surface to satellites. Crustal anomalies reflect the magnetic minerals, which respond to the changing planetary magnetic field. Anomalies are influenced by the geometry of the geological bodies, and magnetic properties of the constitutive rocks. Commonly, magnetism of continental crust has been described in terms of bulk ferrimagnetism of crustal minerals, and much attributed to induced magnetization. Though remanent magnetization was crucial for dating the ocean floor, and is important in mineral exploration, its contribution to continental magnetic anomalies is commonly ignored. Over the last decade studying remanent anomalies in crustal rocks we discovered a new type of remanence, which we called 'lamellar magnetism'. This type of magnetization is due to interface layers of mixed Fe2+ / Fe3+ valence at contacts between exsolution lamellae and hosts of ilmenite and hematite.

The mixed-valence contact layers are placed by chemistry between hematite Fe3+ layers and ilmenite Ti 4+ layers, where they help reduce charge imbalance. Placement requires that the uncompensated spin of contact layers on opposite sides of lamellae be magnetically in phase. This produces a net ferrimagnetic moment per lamella of appx. 4uB per formula unit regardless of lamella thickness, thus net moment is greatest with the greatest density of magnetically in-phase fine lamellae. New studies demonstrate that the proportion of magnetically in-phase lamellae are in samples with strong preferred lattice orientation and is highly correlated with the angle of the statistical basal plane (0001) with respect to the magnetizing field at the time of exsolution, thus yielding strong net moments where a = 0 and the weakest moments where a= 90. Sample coercivity is much higher when ilmenite lamellae are in global linkage with an AF hematite host, than when hematite lamellae are in a paramagnetic ilmenite host lacking global linkage.

Lamellar magnetism is responsible most for the remanent continental magnetic anomalies presented here. It may also be an important contributor to deep-seated anomalies. To explore the effects of temperature and pressure on the solvus of the ilmenite-hematite solid solution, piston cylinder experiments were performed. Samples were held for 28 days at 10 kb and 580C. Samples were characterized by electron microprobe and transmission electron microscopy before and after the piston cylinder experiments. Magnetic properties of the natural and heated samples were compared. Microstructures due to the formation of exsolution lamellae appear to control the magnetic properties in both the natural and experimental samples. Because many of these rocks studied have high NRM values, some $>$ 50 A/m we have also postulated lamellar magnetism may be one of the sources of magnetism for Martian rocks.

Studying the nature of lamellar magnetism has provided other surprises. Some samples of titanohematite with very fine lamellae ($<$ 1nm thick) when cooled below the TN of ilmenite showed very large exchange bias, the largest ever observed in any material. This indicates a magnetic interface coupling between lamellar magnetism in the hematite host and the magnetically hard antiferromagnetic ilmenite. Such exchange bias has even been demonstrated using billion-year-old lamellar magnetism, cooled in zero field down to 5 K before the hysteresis experiment. This and other properties of lamellar magnetism may provide templates for modern magnetic storage technology.

Keywords: Lamellar Magnetism, Magnetic Anomalies, hematite-ilmenite, Exchange Bias

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SEM001-04 Room:301B Time:May 26 09:19-09:36

Mean-field and micromagnetic models for nanoscale magnetism based on ilmenite-hematite solid solutions

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Lamellar magnetism was proposed as a new type of magnetic remanence, carried by uncompensated magnetic layers at interfaces between nanoscale exsolution structures of antiferromagnetic (AFM) hematite and paramagnetic ilmenite. A first experimental proof that the natural remanent magnetization (NRM) of a rock from Modum, Norway, is due to lamellar magnetism, resulted from cooling grains with the original NRM to 5 K, and then measuring their hysteresis loop. The observed large shift of the hysteresis curves showed that exchange bias develops from the untreated NRM. Therefore, the moments which carry the NRM participate in the exchange coupling at the hematite-ilmenite interfaces. The development of physical models to understand the detailed mechanisms of exchange bias and other unusual magnetic properties within homogenous or exsolved minerals of the ilmenite-hematite solid-solution series IlmX (X FeTiO3 (1-X) Fe2O3) is an important research topic. In a general case of isolated nanoparticles embedded in an antiferromagnetic matrix the mechanism of exchange bias originates from the formation of a (quasi)spherical domain wall inside the AF matrix when the particle moment rotates under the influence of an external magnetic field. Micromagnetic calculations show that for isolated nanodots the energy of this domain wall increases nearly quadratically with the deflection angle of the nanodot moment. By introducing the corresponding quadratic energy term in a modified Stoner-Wohlfarth model, a two-parameter family of hysteresis loops is obtained, depending on scaled anisotropy energy and field direction. In case of pure solid solutions, geometric mean-field models implement the varying Fe and Ti concentrations, and the random distribution of Fe ions in the solid solutions. The models either use statistical interactions between sites, whereby they effectively average over all possible configurations, or they describe specific random configurations. Statistical mean-field models are successful in predicting the ferromagnetic (FM) Curie temperatures TC and Ms(T) curves of the IlmX solid solutions. The results depend on the choice of interaction coefficients, which either have been determined by neutron diffraction measurements (Samuelson and Shirane, 1979), by Monte Carlo model fits (Harrison, 2006), or by density-functional theoretic calculations (Nabi et al., 2010) . A special class of mean-field modelling has been suggested by Ishikawa (1957), to estimate the size of interacting clusters in IlmX beyond the FM percolation threshold ($X > 87$), where global ferrimagnetic order breaks down, and only finite ferrimagnetically ordered clusters generate a pseudo-Langevin magnetization curve at temperatures between the FM Curie temperature and the antiferromagnetic Neel temperature TN. Using a numerical inversion method, it is possible to fit measured hysteresis loops of synthetic IlmX samples (X= 92, 97) by improved theoretical pseudo-Langevin curves which depend on cluster-size- and exchange-interaction- distributions. Due to frustrated exchange interactions, the IlmX system can show magnetic spin-glass behaviour at low temperatures, which cannot be modeled by mean-field methods. At T=0, however, the Heisenberg hamiltonian of the spin system has only a finite number of possible values and can be minimized by combinatorial optimization. This at least makes it possible to gain some limited insight into the magnetic behaviour at very low temperatures.

Apart from statistical mean-field models, it is also possible to investigate specific atomic configurations, each corresponding to some fixed Ilm X. These models contain several tens to hundreds of ilmenite unit cells (e.g. 3x3x3 or 5x5x5) with periodic boundary conditions. Their main advantage is that they permit visual inspection of the geometric configuration in relation to the magnetic behaviour.

Keywords: lamellar magnetism, micromagnetic modeling

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SEM001-05 Room:301B Time:May 26 09:36-09:53

Muon spin radiography of sediments

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In this paper, we propose a method to use muon spin radiography as a non-destructive testing method to evaluate the magnetic properties of materials. Muon particles have the ability to penetrate matter ranging from a few mm to a few km, depending on the energy levels. Gigantic objects, such as volcanoes [1], have been imaged using muon absorption radiography by measuring the internal density distribution of the structure. This technique exploits very high energy muons in cosmic rays. It is also possible to produce muons artificially in particle accelerators. These produced muon particles are inadequate (in terms of energy) to penetrate structures as thick as a volcano. However, a higher degree of control over both momentum and polarization is possible and this advantage can allow new applications of muon radiography to be developed. By controlling the momentum of the muon particles, we can control the depth of penetration with greater precision. As a next step, we can also create a three dimensional scan of a specimen by employing a fabricated muon beam with a collimated, narrow spatial spread. Another possibility is to combine muon spin spectroscopy with the mentioned three dimensional scan in order to obtain information about the magnetic properties, also in three dimensions. Muon spin spectroscopy is conducted by using muon beams that have nearly perfect spin alignment in relation to the beam direction. Since muons experience local magnetic fields in their surroundings when they stop in the specimen, they can provide useful information on the local structure of the magnetic domain. This principle is similar to nuclear magnetic resonance, however in this case we implant muons (light protons) instead of using protons that already exist in the material. One of the benefits of muon spin radiography in contrast to conventional techniques is that information is collected from within the structure of the specimen instead of from the outside. In this forum, we demonstrate how muon spin radiography works for a specimen from a banded iron formation (BIF) as the first step application. This can be a good target because the local domain structure of hematite grains in BIF could potentially record the past geomagnetic field. In order to strictly control the muon momentum, a surface muon beam was used in this experiment. The surface muons are produced via decay of pions at rest, therefore they have a momentum of 30 MeV/c. We can calculate the range at which the muon stops and decays to be 0.3 g/cm2 for rock by using the muon energy range relationship. As a result, muon spin asymmetry was measured at this specific depth of the BIF specimen and rapid spin precession due to the internal magnetic field was measured. Results were consistent with the fact that the hematite has parasitic ferromagnetism. The amounts of non-magnetic substances or local magnetic alignments can be calculated by comparing these results with Fe to measure the amount of the non-relaxation component. With the reasonable success of this experiment, there is the potential to extend this concept to applications such as three dimensional tomographic measurements of local magnetic alignments.

References

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Keywords: muon, spin, radiography, geomagnetism, sediments

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SEM001-06 Room:301B Time:May 26 09:53-10:10

Development and application of magneto-optical imaging (MOI) for rock magnetism

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Magneto-optical imaging (MOI) technique measures the magnetic flux threading a magneto-optically (MO) active film, which rotates the polarization direction of transmitted light (Faraday rotation), directly placed on the sample. Through the analyzer of a reflected light microscope, the vertical component of surface magnetic field of the sample is observed. Owing to the thin MO film (5 um) and the small sample-to-film distance (~100 nm), internal structures within metallic grains in meteorites carrying saturation isothermal remanent magnetization is successfully imaged with a spatial resolution better than 10 um. In addition to its high spatial resolution, this technique offers a direct comparison of magnetic and reflected light images, making it a very powerful tool to map and identify the carriers of magnetic remanence in rock samples.

We present results of an integrated study of metallic grains in meteorites, combining MOI, petrography, FE-SEM, TEM, microprobe analyses, and DC demagnetization. Metallic Fe-Ni grains in meteorites have microscopic structures due to Ni diffusion during slow cooling subsequent to metamorphism on their parent body. Previous magnetic studies suggested that tetrataenite (ordered FeNi) is the stable magnetic carriers in these meteorites. On the other hand, mineralogical studies showed that tetrataenite is intimately mixed with other Fe-Ni phases (kamacite and taenite, that contain less than 10 wt% and around 30 wt% Ni, respectively), and forms complex microstructures (see below). However, due to the typical spatial resolution of classical bulk magnetic measurements (~1 mm), it has been so far difficult to isolate the contribution of these different Fe-Ni minerals.

We studied equilibrated ordinary chondrites. Optical and electron microscopies showed two types of micron- to submicron-scaled tetrataenite-bearing microstructures: (1) Zoned taenite particles that consist of a taenite core, surrounded by a "cloudy zone" (20-150 nm large tetrataenite granules embedded in taenite matrix), and a 1-10 um thick tetrataenite rim. (2) Zoneless plessite particles that consist of $<$ 10 um large tetrataenite grains embedded in a kamacite matrix. MOI of saturation remanence showed that only the nm-sized tetrataenite granules in cloudy zone carry very strong remanence. Micron-scale mapping of coercivity of remanence (B_{cr}), by means of DC demagnetization coupled with MOI, combined with FE-SEM and TEM study showed that this cloudy zone has zoning in Ni composition, tetrataenite grain size, and B_{cr}. The center part has finer tetrataenite (20 nm), lower bulk Ni composition (30 wt %) and higher B_{cr} values (up to 1 T) than the outer part (150 nm, 55 wt %, and 400 mT respectively). This result shows good agreement with B_{cr} distribution of bulk ordinary chondrite. Therefore, tetrataenite in the cloudy zone is a potential very stable carrier of extraterrestrial remanence. Moreover, even in weathered meteorites, we can observe natural remanence of metals separated from magnetic signature from oxides. This result demonstrates that MOI is a hopeful technique to discriminate the primary magnetization from altered samples.

Keywords: Magnetic Microscope, Meteorite, Metal, Tetrataenite, Magneto-optical imaging

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SEM001-07 Room:301B Time:May 26 10:10-10:27

Limits of Paleomagnetic Detection: Low-temperature, Helium-free Ultra-high Resolution Scanning SQUID Microscopy

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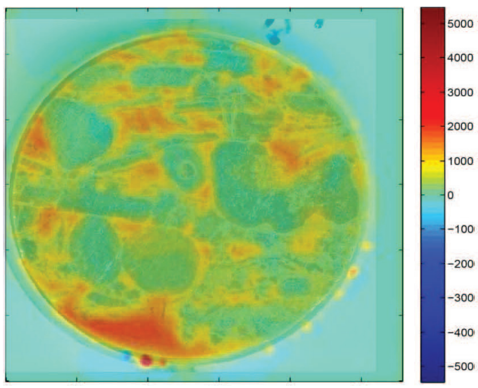
Despite the extraordinary sensitivity of helium-temperature SQUID magnetic sensors, most of their use in geophysics has been in moment magnetometers for paleomagnetic and rock magnetic studies. However, developments in the past decade at Vanderbilt University, Caltech, and at MIT have incorporated them into what is now called the Ultra-High Resolution Scanning SQUID Microscope (UHRSSM). The extreme sensitivity of these instruments ? in some cases capable of imaging the magnetic moment of a single magnetotactic bacterium ? arises from engineering that allows a superconducting sensor in a high vacuum, held at < 5 K, to come within a few tens to hundreds of micrometers from the surface of a room-temperature sample at ambient temperature and pressure. Separating these two regimes, a sapphire window thins to ˜ 25 um near the sensor, and elaborate radiation shielding blocks all but the sensor tip from background heat. By scanning samples in a micron-scale grid beneath the sensor, a map or image of the magnetic field is generated, similar to, but at much smaller scale than, those produced by aeromagnetic surveys. Unlike a magnetic-force microscope, where a magnetized needle is tapped over a small area of a sample, the UHRSSM does not expose the sample to strong magnetic fields and can operate over a much larger area ? from steps only 5 um in size to cover areas up to ˜ 5 x 5 cm. For NRM measurements, the entire assembly must be housed in a mu-metal shielded system with background fields < 10 nT.

Early versions of these instruments were cumbersome to use, requiring separate Dewars for liquid helium and nitrogen. They also needed an elaborate lever mechanism in the vacuum for adjusting the distance of the SQUID sensor from the sapphire window and sample. At Caltech we modified our UHRSSM to operate from a two-stage pulse-tube system manufactured by Cryomech, Inc., which is capable of cooling the sensor to 3.6 K in about two hours. (The same pulse-tube system now is standard on new 2G? magnetometers.) This modification freed us from use of both liquid nitrogen and helium, and minimized the thermal contraction problem to the point where the vacuum lever assembly was not needed. On the other hand, we discovered that the pulse tubes do generate an ˜ 1 Hz magnetic noise of up to 1000 nT amplitude; this is due to their use of rare-earth ferrites with paramagnetic to ferromagnetic transition temperatures < 20 K. This required the addition of a superconducting lead shield to block this noise, and for high-sensitivity measurements, the addition of a second SQUID sensor chip in a gradiometer configuration with real-time noise cancellation.

Applications of the UHRSSM are diverse. It can establish ca. 10,000 independent-grain paleointensity estimates per conventional paleomagnetic sample that offer insight into the dispersion of intra-unit, between-sample paleointensity results. It can assess a conglomerate test on a sandstone or igneous/extraterrestrial (meteoritic) breccia. It can function as a geochemical prospecting tool, discriminating the most pristine from the least-desirable among multiple sulfide paragenetic textures and phases in Archean black shales. And applied to biomagnetic problems, the UHRSSM can localize magnetocyte or magnetosomes within tissue that otherwise can be challenging to detect. The attached image shows a 2.5 cm diameter scan of pre-compaction Archean sulfide nodules that are variably magnetized by an IRM, with relatively nonmagnetic cores. Matrix, in contrast, is strongly remagnetized by pyrrhotite dating ˜500 myr after deposition of the shale.



Keywords: paleomagnetism, rock magnetism, biomagnetism, magnetic microscopy, biogenic magnetite

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Strained magnetite and its remanence properties of Vredefort crater granite

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Vredefort crater granite shows anomalous remanence properties with strong intensity and random orientations of the remanence. These properties were enigmatic but recent drilling study (Carporzen et al. 2010 AGU abstract) reveals the origin of these properties is of lightning strike for some underground samples which can easily be alternating-field (AF) demagnetized in less than 20mT. Still some rock samples show the presence of strong intensity and high coercive coarse magnetite grains which are resistive against stepwise alternating-field demagnetization up to 50mT in scanning MI magnetic microscopy analysis. Here we show a collaborative study of micro-Raman spectroscopy, magnetic Kerr microscopy and a magnetic force microscopy (MFM) for the highly resistive coarse magnetite grains in Vredefort granite. The micro-Raman spectroscopy study reveals the presence of magnetite with a A_{1g} mode (680 cm^{-1}) and hematite as a lamellae in the high coercive coarse-grained magnetite along $\{111\}$ plane which is same plane as twinning of magnetite. The magnetite A_{1g} mode shows an obvious blue-shift from normal magnetite of 667cm^{-1}. The magnetic Kerr microscopy and MFM studies of the same grain showed striped magnetic domain walls along $\{111\}$ plane. The same blue-shifted Raman mode of magnetite and the presence of striped domain wall have been observed in strained magnetite artificially deposited on $SrTiO_3$ film by Chen et al. (2008). Also their hysteresis study showed the strained magnetite has a larger coercivity, and they concluded that these observations result from the formation of more pinning centers induced by high density of defects grown along specific direction like $\{111\}$. Therefore, we can conclude analogically that our Vredefort magnetite is affected by strains due to impact and their strain-induced domain wall pinning causes high coercive strong intensity of the remanence of coarse-grained magnetite in Vredefort crater granite.

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Ultrafine-scale magnetostratigraphy with SQUID microscope: Application to ferromangenese crust and other materials

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Scanning SQUID microscopy enables us to do mapping of magnetic field over thin sections of geological samples at submillimeter scale. With this new technique, ultrafine magnetostratigraphy can be achieved on geological sample which we could not observe the polarity pattern due to the limitation of the spacial resolution. In the presentation, we show a successful example on marine ferromanganese crust and extend the possibility in the future. Hydrogenetic ferromanganese crusts are iron-manganese oxide chemical precipitates on the seafloor that grow over periods of tens of millions of years. Their secular records of chemical, mineralogical, and textural variations are archives of deep-sea environmental changes. However, environmental reconstruction requires reliable high-resolution age dating. Earlier chronological methods using radiochemical and stable isotopes provided age models for ferromanganese crusts, but have limitations on the millimeter scale. For example, the reliability of 10Be/9Be chronometry, commonly considered the most reliable technique, depends on the assumption that the production and preservation of 10Be are constant, and requires accurate knowledge of the 10Be half-life. To overcome these limitations, we applied an alternative chronometric technique, magnetostratigraphy, to a 50-mm-thick hydrogenetic ferromanganese crust (D96-m4) from the northwest Pacifi c. Submillimeter-scale magnetic stripes originating from approximately oppositely magnetized regions oriented parallel to bedding were clearly recognized on thin sections of the crust using a high-resolution magnetometry technique called scanning SQUID (superconducting quantum interference device) microscopy. By correlating the boundaries of the magnetic stripes with known geomagnetic reversals, we determined an average growth rate of 5.1 +- 0.2 mm/m.y., which is within 16% of that deduced from the 10Be/9Be method (6.0 +- 0.2 mm/m.y.). This is the finest-scale magnetostratigraphic study of a geologic sample to date. Ultrafine-scale magnetostratigraphy using SQUID microscopy is a powerful new chronological tool for estimating ages and growth rates for hydrogenetic ferromanganese crusts. It provides chronological constraints with the accuracy promised by the astronomically calibrated magnetostratigraphic time scale (1-40 k.y.). The technique can be extended to other geological objects such as stalagmite, hydrothermal deposites, desert varnish, etc. An analogue of dersert varnish would be found on Mars, which might have recorded ancient Martian magnetic field.

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Magnetic anomaly lineations in the Gulf of Aden

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The Gulf of Aden is located in the Indian Ocean between Yemen on the south coast of the Arabian Peninsula and Somalia in Africa. The Gulf of Aden is a young ocean basin formed by the rifting of Arabia away from Somalia. The Arabian plate moves away from Africa in a NE direction, at a rate of about 2 cm/yr. The rifting started from Oligocene.

Seafloor spreading started at 17.6 Ma in the eastern part of the Gulf of Aden (Fournier et al., 2010) and propagated westward into the Arabia-Africa continent (Manighetti et al., 1997). It reached the Afar hotspot area about 10 Ma (Audin et al., 2001). The spreading system continues to interact with the hotspot up to the present. Tamsett and Searle (1988) exposed that strike of segmentations of the spreading centers in the Gulf of Aden is NW-SE, although the trend of the spreading system is ENE.

To expose the seafloor spreading history of the Gulf of Aden west of the Alula-Fartak Fracture Zone, we examined magnetic anomaly lineations. Most of the geomagnetic data used in our study were collected by the cruises by R/V L'Atalante in 1995 and R/V Hakuho-maru in 2000. Geomagnetic data collected by other ships were also examined.

Elongated negative magnetic anomalies are observed over the spreading centers. The elongated anomalies are parallel with the spreading centers. The elongated magnetic anomalies west of 46 30'E have an E-W trend around the spreading centers. Our identification of magnetic anomaly lineations indicates a symmetric seafloor spreading, although Leroy et al. (2004) showed an asymmetric seafloor spreading of the Sheba Ridge, east of our study area. It also indicates a westward decrease in spreading rates in our study area. The kinematics of the Arabia plate changed about 5 Ma, but our results did not show any coeval change in spreading rates of the spreading system in the Gulf of Aden.

Keywords: Gulf of Aden, magnetic anomaly lineations, slow-spreading system

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Submersible magnetic observations at a back-arc spreading center of the Mariana Trough at 17N

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We surveyed the Mariana Trough in the western Pacific to understand detailed volcanic and crustal formation processes of the back-arc basin. Three dives of the Japanese submersible Shinkai 6500 were made in the axial valley situated in the spreading center of the 17N segment [Fujiwara et al., InterRidge News, 2008]. The 17N segment is suggested to have ever been in vigorous magmatic stage, because sheet lava flows, suggesting a high rate of eruption, occupy the seafloor even the slow spreading with a full-rate of ˜3 cm/yr [Deschamps et al., G3, 2005; Asada et al., G3, 2007]. The sheet lavas and pillow lava mounds suggesting a low effusion rate coexist in the axial valley. Near-seafloor magnetic observations provide high-resolution magnetic anomaly that is valuable for studies of detailed magnetization structure. The magnetization intensities relate to relative age differences of the lavas, therefore the magnetic data provide a geophysical evidence for discussion whether the segment is in the magmatic waxing or waning stage at present. The deep-sea magnetometer installed on the submersible was designed to measure three components of the geomagnetic field. Because the trough is situated at low magnetic latitudes, vector components have advantages over using only total field anomaly. The measured magnetic field was affected by motion and magnetization of the submersible. The effects were determined and necessary corrections were applied by using the formulation of Isezaki [Geophys, 1986]. After the calibration, the ˜4000 nT effect of the submersible was reduced to a residual less than 500 nT. Two dives traversed the western and eastern flanks of the valley in the segment center, and the other dive was on the western flank slightly in the segment end. Magnetic anomalies with large-amplitude and short-wavelength (several tens of meters) were observed near-seafloor. Particularly high amplitude anomalies (up to 5000 nT) were observed in the western flank near the middle portion of the axial valley in the segment center where sheet lavas were dominant. High magnetization intensity (up to 50 A/m) was estimated over the flank, therefore the sheet lava flows are likely young in age and recently emplaced. It suggests the segment is still magmatically vigorous at present. On the other hand, low amplitude anomalies suggesting old lava flows were observed in the eastern flank of the valley. The amplitudes in the western flank to the segment end are moderate and fall somewhere in between. The sheet lavas there seem to be slightly old. It may suggest infrequent magma effusion compared to the segment center. These magnetic age estimations are consistent with observations of sediment deposition from visual inspections and measurements of a sub-bottom profiler attached on the submersible, and also sampled rock magnetization and geochemical measurements. The across-axis magnetic structure along the dive path (a distance of ˜2 km) shows the magnetization intensity decreased toward the off-axis, suggesting the seafloor age increases toward the off-axis. However the detailed variation of the magnetization distribution does not show simple seafloor age increment in proportion to distance from the spreading center because there is no clear correlation between the across-axis distribution of magnetization intensity and a compiled dataset of paleointensity variation [e.g. Sint-800: Guyodo and Valet, Nature, 1999]. It implies the complexity of the crustal formation process. A possible explanation is that lava eruption at the segment was not focused on the fixed and stationary volcanic axis, but was dispersed rather broad volcanic zone because of the enhanced magmatic activity. Otherwise ridge jumps at small distances occurred. And/or new sheet lava flows traveled a long distance and overlapped old lava flows, and the lavas overprinted the seafloor magnetization. As the result, the sequential paleointensity variation was not recorded.

Keywords: Mariana Trough, back-arc basin, submersible, magnetic anomalies, magnetization of ocean crust, volcanic processes

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Near-bottom magnetic surveys around hydrothermal sites in the southern Mariana Trough using AUV

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Near-bottom magnetic survey by using an AUV is an effective method to reveal the detailed magnetic anomaly signatures of ocean floor such as those around hydrothermal vent sites. In order to detect signals of hydrothermally altered rocks in the southern Mariana Trough, the measurements of total intensity and three-components of the geomagnetic field are conducted by using AUV URASHIMA during the YK-09-08 cruise. Four three-axis fluxgate type magnetometers and overhauser type magnetometer are attached on AUV URASHIMA.

During the cruise, three components of geomagnetic field by the four fluxgate type magnetometers are successfully obtained along the all dive tracks of AUV URASHIMA. Total intensities of geomagnetic field by the overhauser magnetometer are only collected along almost E-W oriented observation lines due to the sensitivity of the sensor.

We will present vector magnetic anomaly field around hydrothermal sites in the southern Mariana Trough and distribution of crustal magnetization derived from the inversion method.

Keywords: magnetic anomaly, Mariana Trough, AUV, hydrothermal vent

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Some tips on data reduction for practical magnetic survey

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One of the most popular instruments for magnetic survey on land is proton magnetometers for its stability of the obtained data and convenience of use at the field. Recent years, the type of the proton magnetometer utilized the Overhauser effect has been often used above all. The Overhauser proton magnetometer has the ability of much more stability of measurement which can acquire data even in the high gradient magnetic field. The component of the data obtained by proton magnetometer is usually only the total intensity of the geomagnetic field.

Magnetic survey within a limited area usually requires simultaneous magnetic observation at a fixed point for a reference in order to remove time-varying component of the geomagnetic field. The fixed point observation, however, is sometimes failed to be obtain due to non-availability or breakdown of instruments. On the time of no reference data, here an example of making synthetic reference data is introduced.

On times we are sometimes suffered from the intense magnetic field from artificial obstacles such as guard rail along the road, ditches made by iron and concrete, or metal net or wires around there. An example of reduction such noises is also introduced here. The method of reduction is fitting noise data to theoretical magnetic dipoles using a kind of inversion.

These examples of reduction of magnetic data are applied practical data at a field of a pottery site where the magnetic anomalies due to thermal remanent magnetization are expected.

The magnetic survey was carried out around the Shiraiwa pottery site Senboku city, Akita prefecture. The production of potteries, however, had ceased more than one hundred years ago.

Since the Shiraiwa pottery site is the oldest one in Akita prefecture, the value as a historical heritage is very high. Consequently the exact knowledge of the positions and their scales of the kiln vestiges with buildings in surrounding area are also required.

Keywords: magnetic survey, proton magnetometer, data reduction, inversion

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Magnetic imaging as an inverse boundary value problem: Application to mapping of the lunar magnetic anomalies

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Magnetic imaging of the static magnetic field at the surface is mathematically regarded as solving an inverse boundary value problem. It is known that there are three types of the boundary value problem: Dirichlet (the first kind), Neumann (the second kind) and Cauchy (the third kind) problems. For example, the magnetic field at any point over the surface is given by the surface integration of potential values (Dirichlet type), radial components (Neumann type) or magnetic charges (Cauchy type). The kernel of the surface integral is determined from a kind of the boundary value and morphology of the boundary surface. Inversely the boundary value is obtained from observations over (or inside) the boundary surface by solving an inverse boundary value problem such as the deconvolution or the downward continuation.

There have been several equivalent source models of the magnetic imaging at the boundary surface. The equivalent vertical magnetization at the surface is considered to be an inversion of the Dirichlet problem, so that the obtained vertical magnetizations express the surface potential. The equivalent source model of horizontal currents or horizontal magnetizations at the surface is an inversion of the Neumann problem. Although the boundary surface should be closed or infinite in these problems, the methods are approximately applicable to an unclosed region if effects of boundary values in other part of the surface are negligible. In this case, the observation is assumed to be filtered with a rectangular window of a closed or infinite surface. If the observation is distributed along a track, constraints from the discrete sampling should be considered in the analysis, especially in the downward continuation. Therefore, it is needed for improvement on the magnetic imaging method to carefully consider a kind of the boundary value, mathematical properties of the kernel function, observational conditions, noise sources and assumptions of modeling.

Providing the lunar magnetic anomaly map is regarded as the magnetic imaging by a satellite magnetometer. Previous maps of vector fields of the lunar magnetic anomaly have been provided at a certain altitude such as 30 km and 100km. However, those maps show insufficient spatial resolutions when compared with geological and topographical data on the surface. We have developed a new method for the surface vector mapping of the lunar magnetic anomalies observed by a satellite magnetometer. We will discuss the method of surface mapping of the lunar magnetic anomalies and show several examples of mapping results based on the Kaguya and Lunar Prospector datasets.

Keywords: magnetic imaging, inversion, boundary value problem, Moon, magnetic anomaly

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Equivalent Pole Reduction: concept and advantages

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We developed Equivalent Pole Reduction (EPR) method for restoring the 3-d distributions of the lunar magnetic field from the satellite data (Lunar Prospector and Kaguya). It is essentially a variant of equivalent source method. It uses magnetic monopoles instead of widely used magnetic dipoles.

The EPR has several advantages to the Equivalent Source Dipole (ESD) method. Ease of calculation, stability of inversion and small edge effects are some of the advantages. It has large advantage with the satellite or airborne data in which the altitude is not always pre-determined, but will work with other data like shipborne or microscale measurements since it uses advantages of the nature of potential field.

Keywords: Magnetic mapping, Equivalent source method, Planetary magnetism